Introduction to an Online Coupled Ocean-Atmosphere Radiative Transfer Model

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1. Description of the Model

A web site has been established recently at the NASA Langley Research Center for online simulation of solar radiation using the Coupled Ocean-Atmosphere Radiative Transfer (CO-ART) model (shown in Figure 1). This provides a tool to calculate radiances and irradiances (fluxes) at individual wavelengths or in a spectral band specified by the user at any level in the air and water. It can also calculate the water-leaving radiances at the ocean surface. Users just follow the setup menu (as shown Fig. 1) to select or specify the atmosphere (atmospheric profile, aerosol type, AOT and precipitable water, etc.) and the ocean (ocean depth, wind speed, Chl, CDOM, etc.) as well as the calculation type and output levels.

COART is established on the Coupled DIScrete Ordinate Radiative Transfer (CDISORT) or the Coupled DISORT, which was developed from DISORT, a publicly distributed software for radiative transfer by NASA. Because DISORT does not consider the refractive index variation in the medium, it is applicable only to radiative transfer problems within a medium where the refractive index variation is negligible, such as in the atmosphere with the land or ocean surface treated as bottom boundary. However, it is well known that the optical properties within the ocean affect the upwelling radiation in the atmosphere and the the atmospheric properties affect the radiation penetrated into the ocean. In other words, the radiation in the atmosphere and in the ocean interact with each other and the radiative transfer process in the atmosphere and ocean should be treated consistently as one coupled system. This was done in CDISORT by including the refractive index into the radiative transfer equation. The detailed formulation and solution of the radiative transfer equations in the coupled atmosphere-ocean system by using the discrete ordinate method was given by Jin and Stamnes (1994).

However, the solution presented in Jin and Stamnes (1994) was for the flat ocean surface. In reality, the calm ocean conditions is very rare. The ocean surface roughness affects the reflection and transmission of the incident radiation at the ocean surface and, therefore, the albedo and solar heating in the ocean, as well as the sun glint pattern. We have recently included the wind blown ocean surface roughness by using the Cox and Munk (1954) surface slope distribution which is a function of wind speed (Jin et al., 2002). The sun glint induced by the surface roughness is included accordingly.

Because the radiative transfer equation, which includes the refractive index and surface roughness, is solved consistently in the coupled system, COART considers the ocean just as additional ‘atmospheric layers’ but with significantly different optical properties. It treats the scattering and absorption in both the atmosphere and the ocean explicitly. Therefore, unlike the usual atmospheric radiative transfer models which take the ocean surface as the lower boundary with given reflectivity, COART can simulate the ocean surface reflectance.

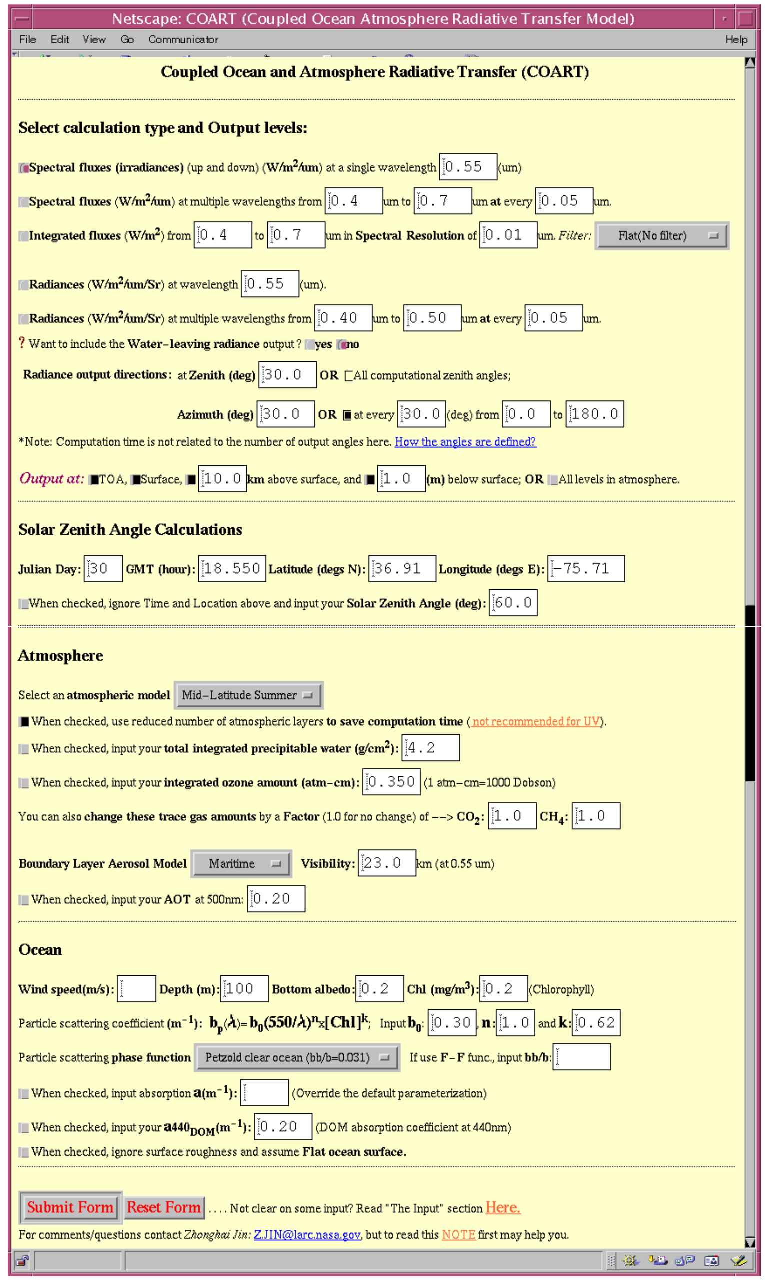

Fig. 1 The web page for CO-ART.
http://snowdog.larc.nasa.gov/jin/rtset.html

2. Examples of Calculation by COART

The following figures present some examples of calculations. Observation data, when available, are also shown for comparison. All the radiation measurements are taken over the Chesapeake Lighthouse platform or over aircraft at NASA's CERES Ocean Validation Experiment (COVE) site, which is 25km east of the Virginia Beach in the Atlantic Ocean. The aerosol optical properties, precipitable water (PW), wind speed, Chl and the absorption properties for soluble and particulate materials in the ocean, which are used for model input, are also from in-situ measurements at COVE.

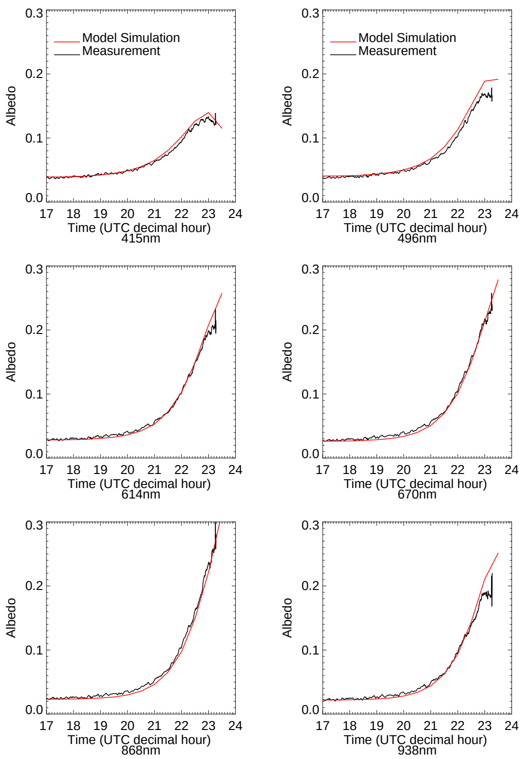

Fig. 2. Modeled (red) and measured (black) ocean albedo in the six MFRSR channels at COVE on July 31, 2001.

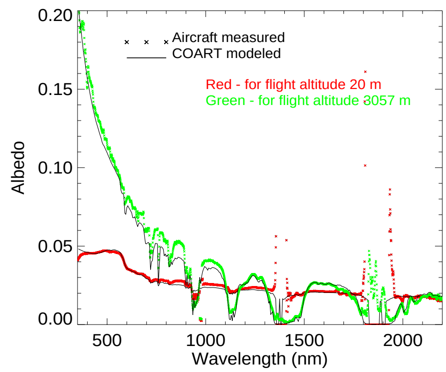

Fig. 4. A comparison of the modeled and aircraft measured albedo over the ocean in the vicinity of COVE on August 12, 2002.

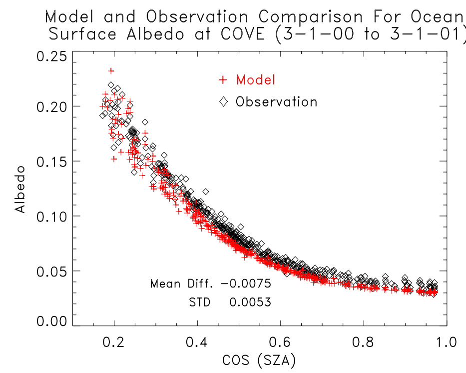

Fig. 5. Modeled and measured broadband ocean surface albedo at COVE under clear skies for a whole year.

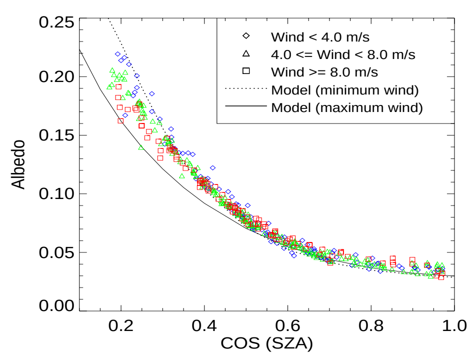

Fig. 6. Wind effects on ocean surface albedo. The observed albedo as a function of the cosine of SZA are plotted in three wind categories. The dashed line and the solid line are the modeled albedo with the minimum wind (0.48 m/s) and maximum wind (14.0 m/s) of the observations, respectively. The mean AOD and PW of measurements were used in model calculations.

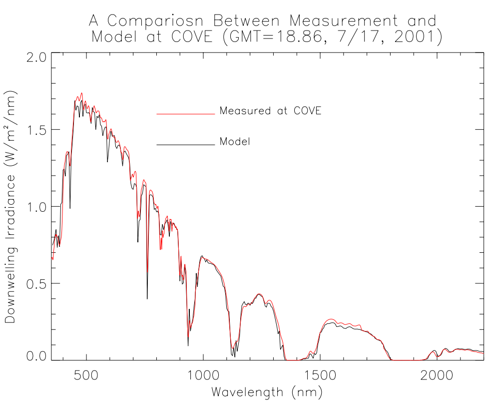

Fig. 3. An example of modeled and measured downwelling spectral irradiances.

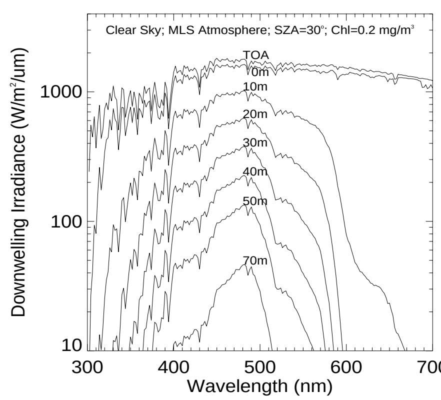

Fig. 7. Modeled downwelling irradiances at the TOA, surface and various depths in the ocean under clear sky conditions

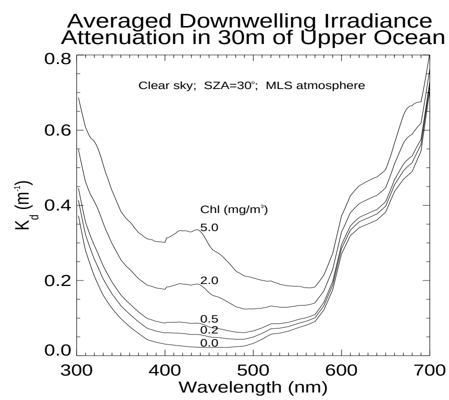

Fig. 8. Modeled downwelling flux attenuation coefficients averaged in the 30 m of upper ocean for different chlorophyll concentrations.

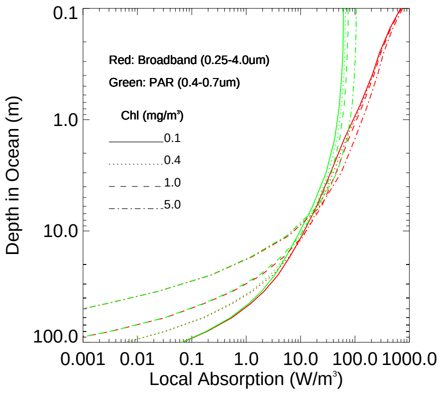

Fig. 9. Modeled local solar absorption as a function of depth. Note that the absorptions for the broadband and the PAR are overlapped at depth of about 10 m, indicating that most of radiation outside of PAR is absorbed in the few meters of the top layer. Clear sky; SZA=30°; MLS atmosphere.

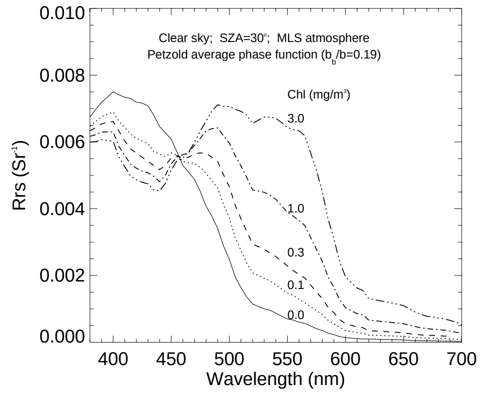

Fig. 10. Modeled remote sensing reflectance (Rrs = Lw / Ed) for different Chls. Note that the optical properties for ocean particles are based on the parameterization of Gordon and Morel (1983), which are chlorophyll related only. The actual absorption and scattering may be very different, which could result in very different Lw and Rrs, especially in the blue.

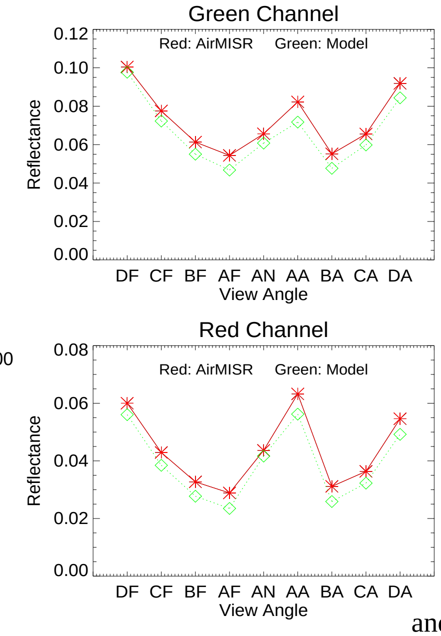

Fig. 11. The equivalent reflectance measured from nine view angles by AirMISR at 20 km above the ocean at COVE and comparison with model simulation. Note that the view directions 'AA' and 'AN' are right in the sun glint region.

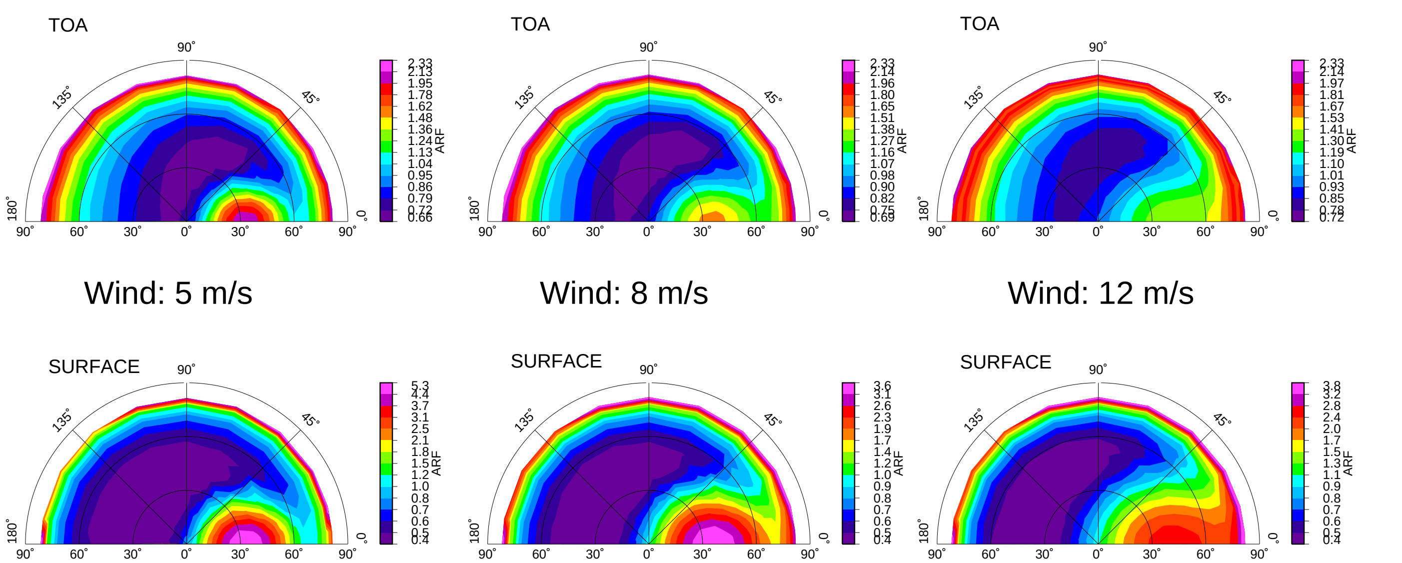

Fig. 12. Modeled BRDF at the TOA and the ocean surface for three different wind speeds. Clear sky; SZA=30°; MLS atmosphere; no aerosol. Note the sun glint variations with wind speed.

3. Features to be Added

COART is still under development. The online model does not have the full capability as the offline model yet. Some new features will be added to the online input/output menu. These include but not limited to the following:

- Input vertical profile of water vapor and aerosol.
- Input aerosol optical properties at multiple wavelengths.
- Input Chl profile in ocean.
- Input clouds.
- Implement the band model for fast computation over broadband.

If you want to receive the upgrade information, go to **http://snowdog.larc.nasa.gov/jin/rtnote.html**, and add your email to the mailing list.

4. References

Cox, C., and W. Munk, 1954: Measurement of the roughness of the sea surface from photographs of the sun's glitter, J. Opt. Soc. Am., 44, 838-850.

Jin, Z., and K. Stamnes, 1994: Radiative transfer in nonuniformly refracting layered media: Atmosphere-ocean system. Appl. Opt., 33, 431-442.

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